Partonic Equation of Sate in High-Energy Nuclear Collisions

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(1) Introduction

(2) Bulk properties at RHIC

- partonic collectivity from multi-strange hadrons

(3) Summary

Physical Goals at RHIC

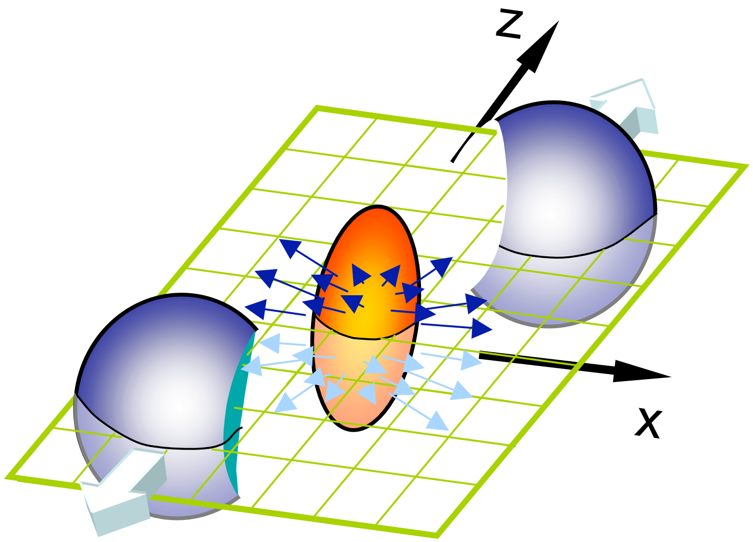
Identify and study the properties of matter (EoS) with partonic degrees of freedom and determine the QCD phase diagram.

Penetrating probes
- direct photons, leptons
- "jets" and heavy flavor

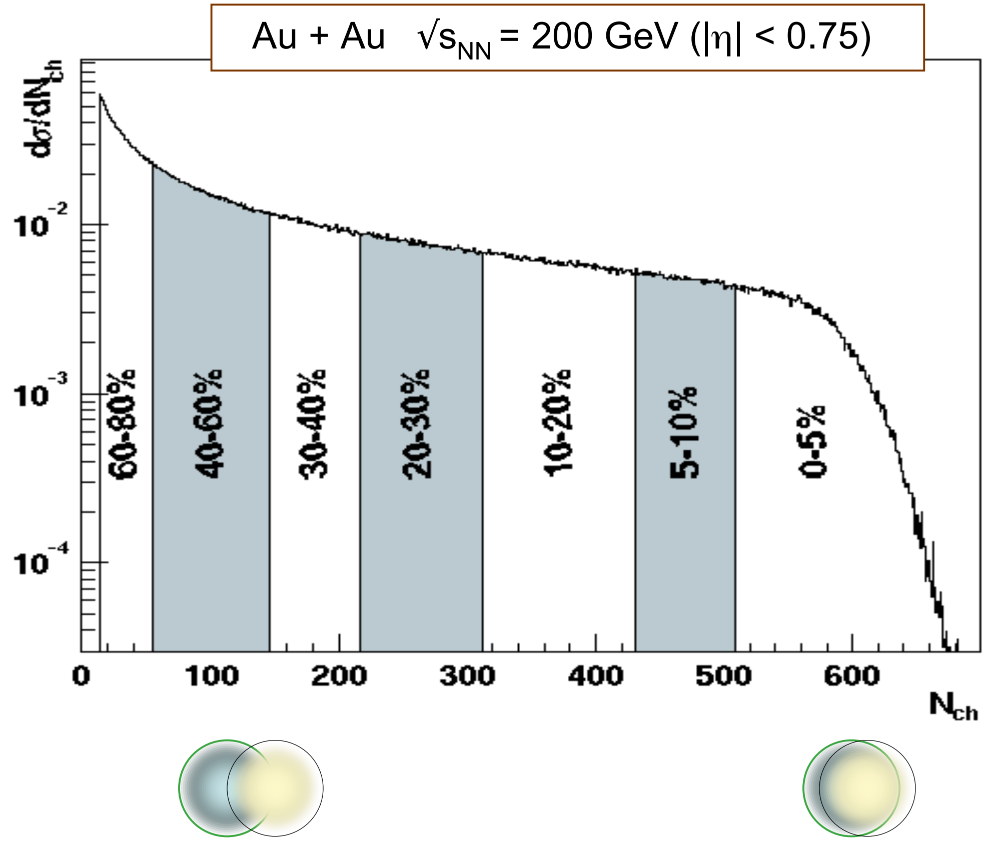
Bulk probes
- spectra, v_1, v_2 …
- partonic collectivity

Hydrodynamic Flow = ***Collectivity*** $\otimes$ Local Thermalization

Collision Geometry, Flow



Non-central Collisions



Number of participants: number of incoming nucleons in the overlap region

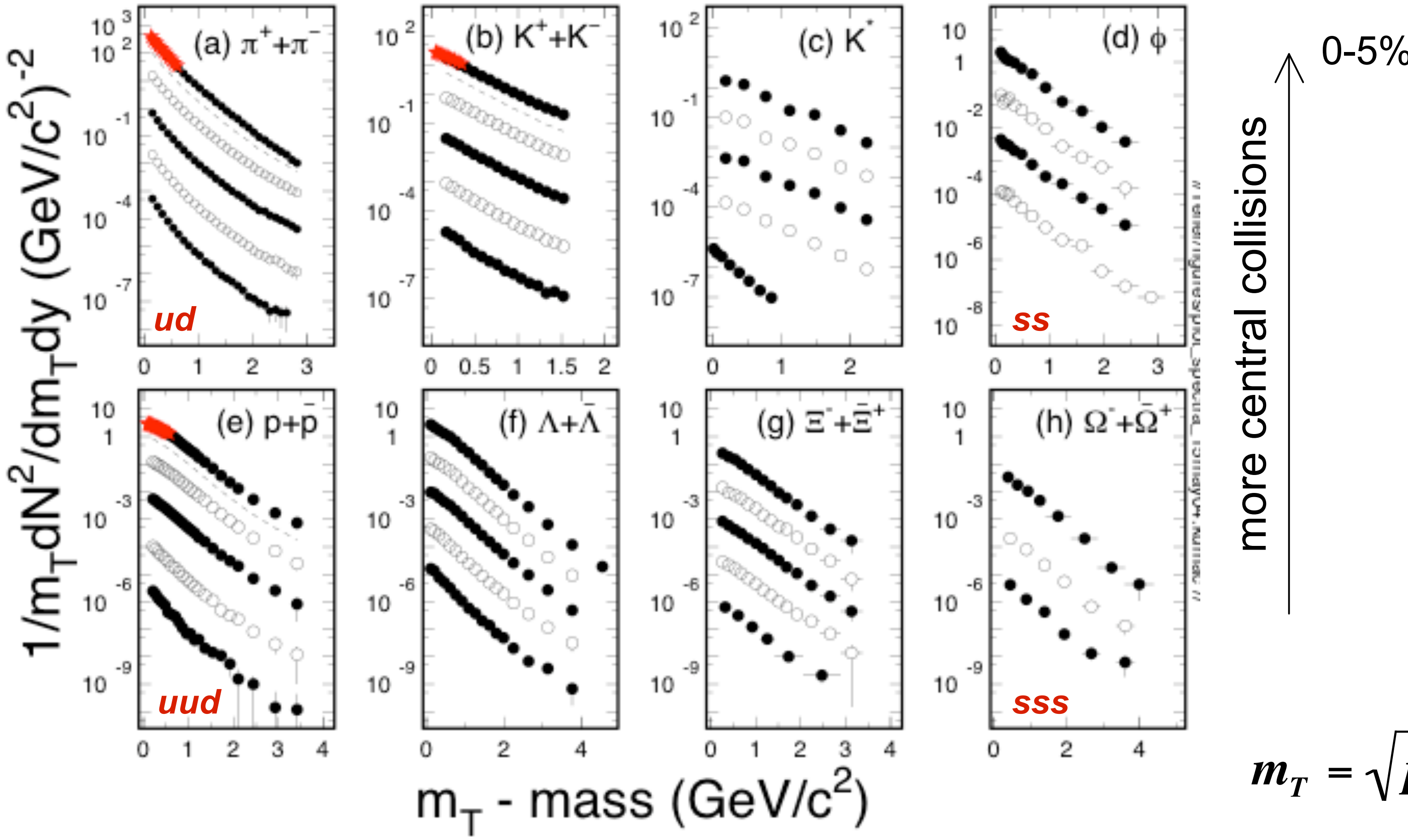
Number of binary collisions: number of inelastic nucleon-nucleon collisions

Charged particle multiplicity ⇔ collision centrality

Reaction plane: x-z plane

Hadron Spectra from RHIC

p+p and Au+Au collisions at 200 GeV

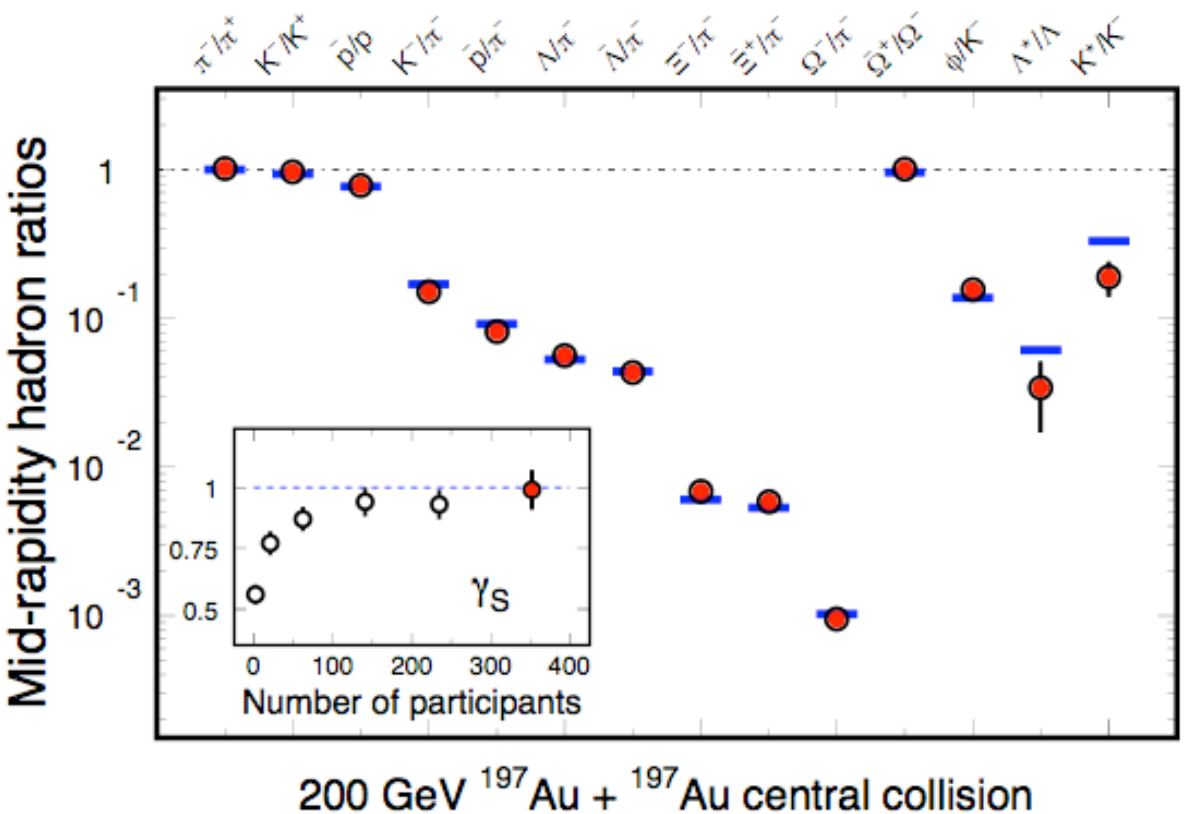


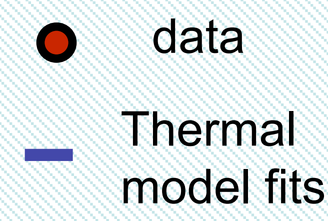
$$m_T = \sqrt{p_T^2 + m^2}$$

Multi-strange hadron spectra are exponential in their shapes.

STAR white papers - Nucl. Phys. A757, 102(2005).

Yields Ratio Results





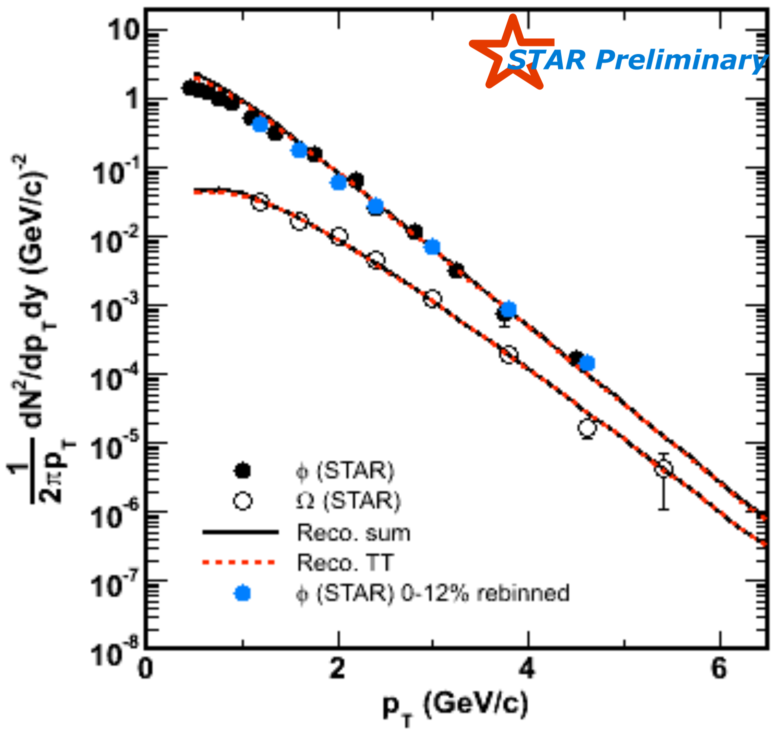
T_{ch} = 163 ± 4 MeV

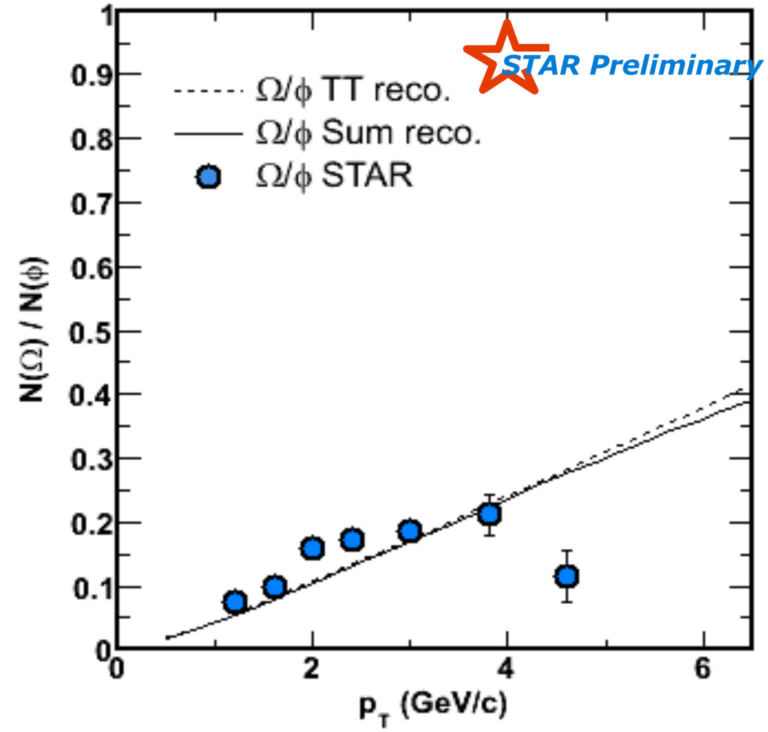
μ_B = 24 ± 4 MeV

- In central collisions, thermal model fit well with γ_S = 1. **The system is thermalized at RHIC.**
- Short-lived resonances show deviations. **There is life after chemical freeze-out.**

RHIC white papers - 2005, Nucl. Phys. _A757_, STAR: p102; PHENIX: p184.

Multi-strange Hadron Ratios



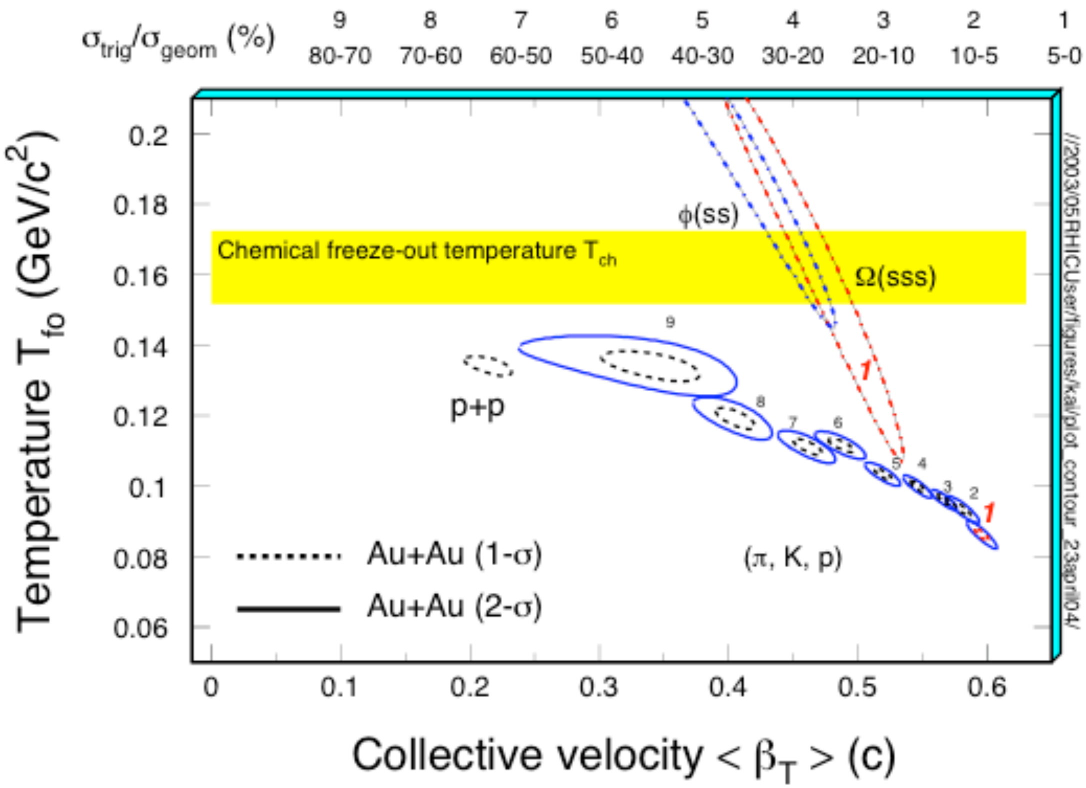


In heavy ion collisions at RHIC, up to p_T ~ 4 GeV/c, (*model predicts 8 GeV/c) the strangeness production is dominated by the thermal like processes.

**Hwa and Yang, nucl-th/0602024; STAR: nucl-ex/0703033*

Blast Wave Fits: T_{fo} vs. $\langle\beta_T\rangle$

200GeV Au + Au collisions



Multi-strange hadrons freeze-out with higher T_{fo} ($\sim T_{ch}$) and smaller $\langle\beta_T\rangle$

1) π, K, and p change smoothly from peripheral to central collisions.

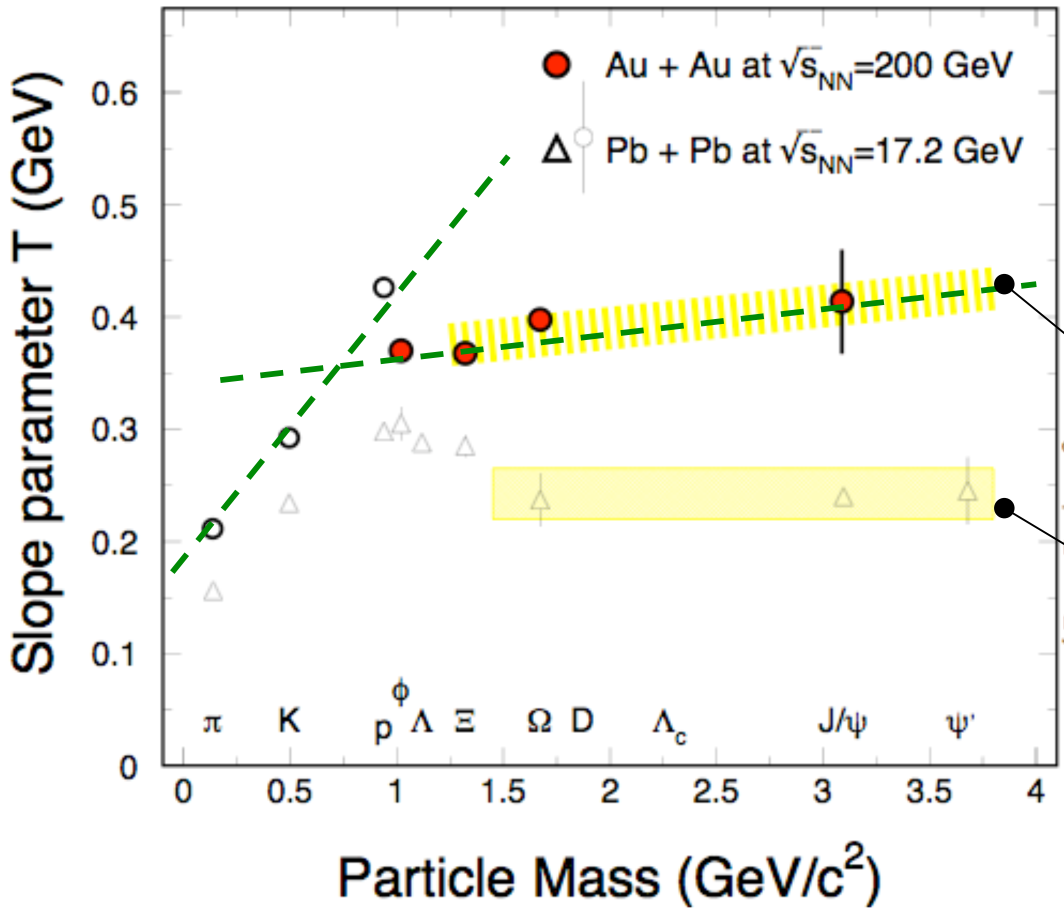
2) At the most central collisions, $\langle\beta_T\rangle$ reaches 0.6c.

3) Multi-strange particles ϕ, Ω are found at higher T and lower $\langle\beta_T\rangle$

➪ **Sensitive to early partonic stage!**

STAR: NP**A715**, 458c(03); *PRL* ***92***, *112301(04)*; ***92***, *182301(04).*

Slope Parameter Systematics



$$f = A \bullet \exp\left(-m_T / T_{slope}\right)$$

<u>RHIC results:</u>
Collective motion for multi-strange and charm hadrons!

$\langle \beta_p \rangle \geq$ **0.2c**

<u>SPS results:</u>
No collective motion for multi-strange and charm hadrons!

At RHIC, φ, Ξ, Ω, and J/ψ show collective motion in 200 GeV Au + Au central collisions!

PHENIX (π, K, p, J/ψ): PRC69, 034909(04), QM05; STAR (φ, Ξ, Ω): QM05.

EOS Parameters at RHIC

In central Au+Au collisions:

- partonic freeze-out:

***T_p = 165 ± 10 MeV** weak centrality dependence

$\langle\beta_p\rangle \geq 0.2$ (c)

- hadronic freeze-out:

***T_{fo} = 100 ± 5 (MeV)** strong centrality dependence

$\langle\beta_{fo}\rangle = 0.6 \pm 0.05$ (c)

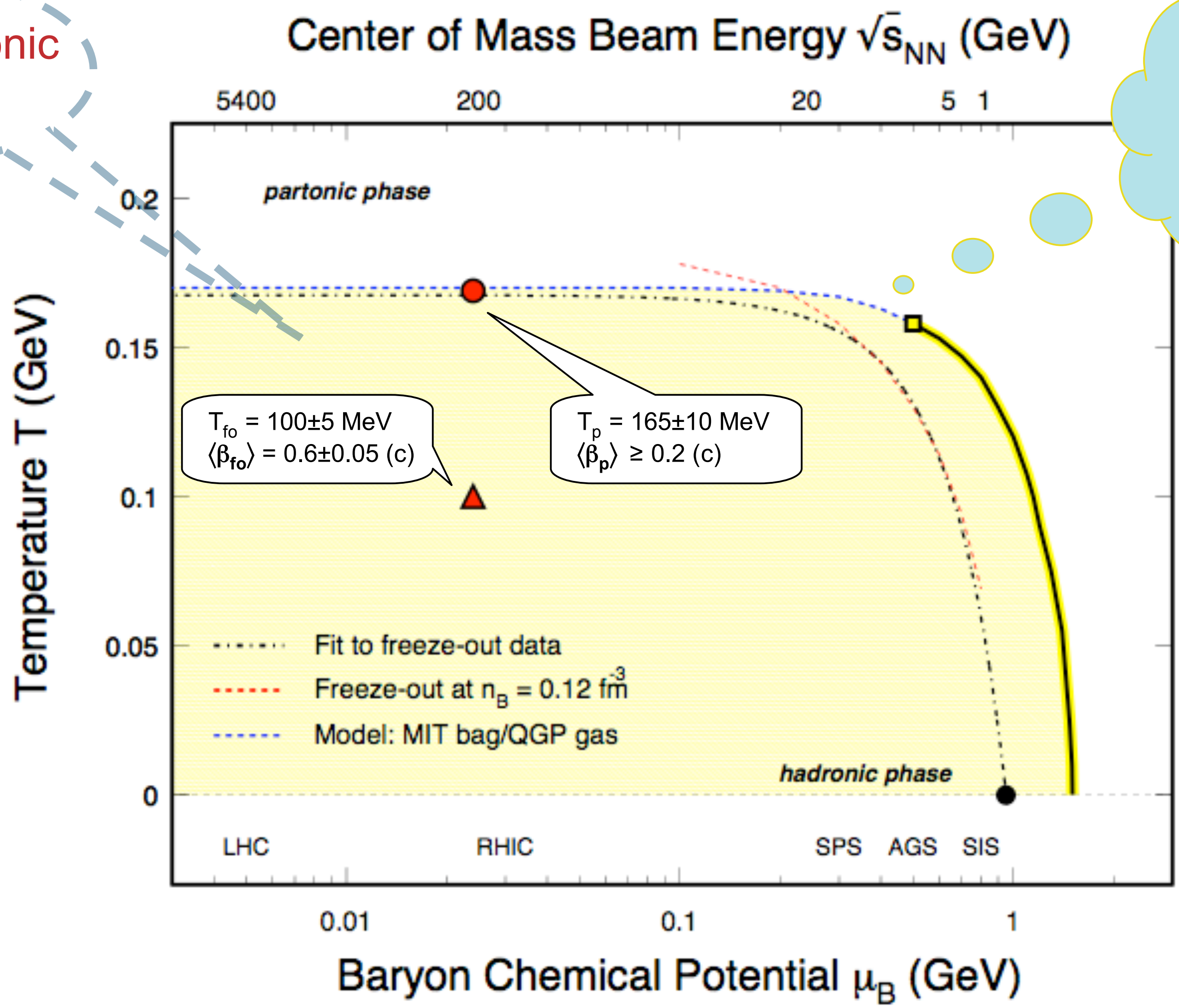
Systematic study are needed to understand the centrality dependence of the EOS parameters

* *Thermalization assumed*

QCD Phase Diagram

deep partonic ocean

LHC
RHIC-II



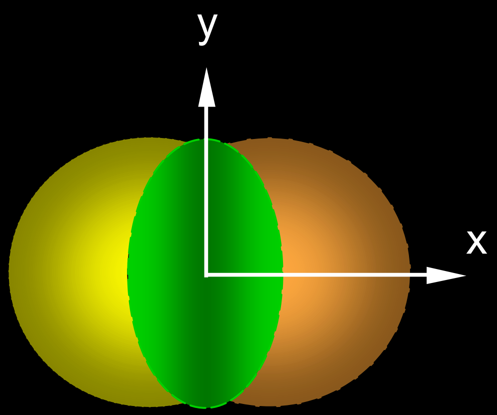
phase boundary? (hadronic shore)

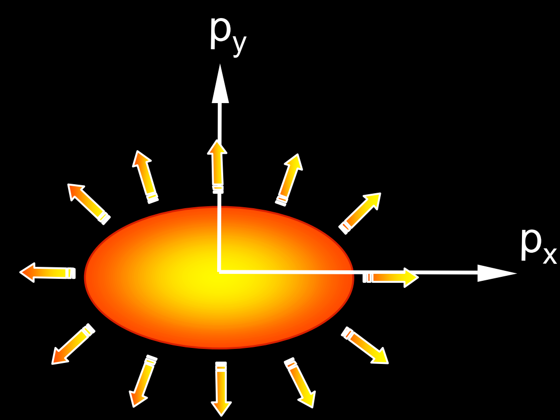
RHIC energy scan

CBM at GSI

Anisotropy Parameter v_2

coordinate-space-anisotropy ➪ momentum-space-anisotropy

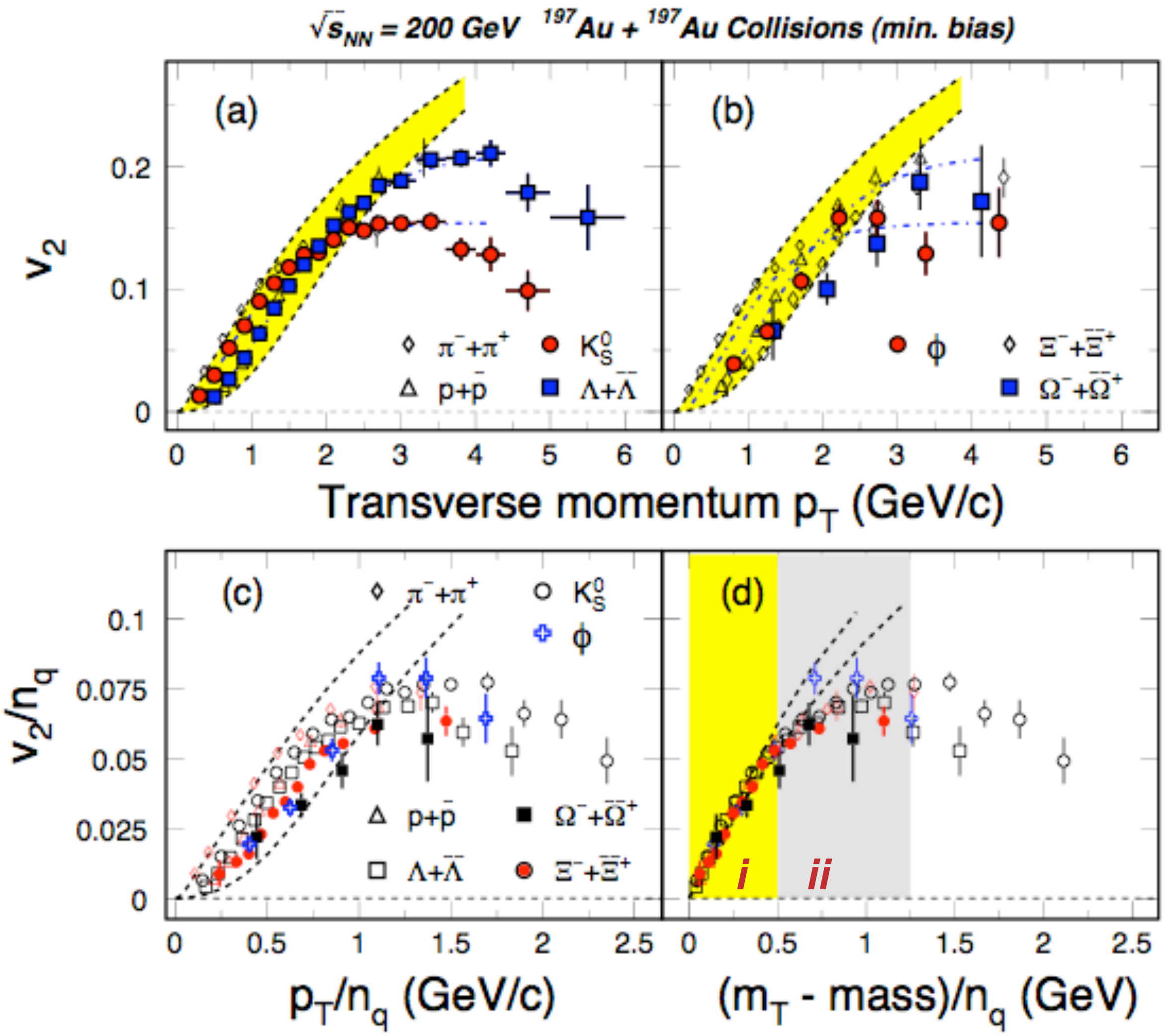




$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

Collectivity, Deconfinement at RHIC



- v_2 of light hadrons and multi-strange hadrons
- scaling by the number of quarks

At RHIC:

➪ **m_T - NQ scaling**

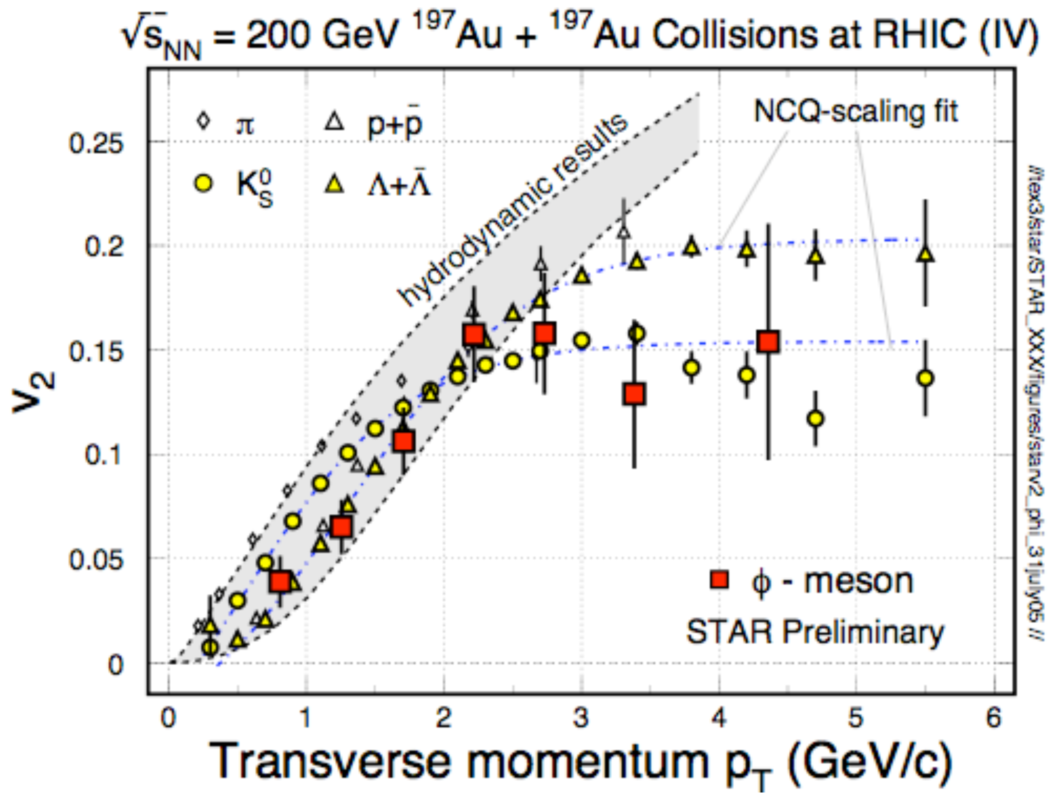
➪ **Partonic Collectivity**

➪ **Deconfinement**

*PHENIX: PRL**91**, 182301(03)*
*STAR: PRL**92**, 052302(04), **95**, 122301(05) nucl-ex/0405022, QM05*

S. Voloshin, NPA715, 379(03)
*Models: Greco et al, PR**C68**, 034904(03)*
Chen, Ko, nucl-th/0602025
*Nonaka et al. **PLB583**, 73(04)*
*X. Dong, et al., Phys. Lett. **B597**, 328(04).*
….

ϕ -mesons Flow: Partonic Flow



ϕ-mesons are very special:

- they do not re-interact in hadronic environment
- they are formed via coalescence with thermal s-quarks
- they show strong collective flow

STAR: nucl-ex/0703033

Summary

In Au + Au collisions at RHIC:

(1) Hadron yields in the state of equilibrium - chemical freeze-out near the transition temperature

(2) The yields $N(\Omega)/N(\phi)$ ratios indicate thermalization

(3) Partonic collectivity and de-confinement

Next step: test thermalization with heavy flavor hadrons